Given:

- part drawing with two views
- dimensions in mm

a) The stock must have a larger OD than the largest OD of the part, a smaller OD than the smallest OD of the part, and length greater than that of the part by enough that it can be held in a lathe chuck. Therefore, an appropriate choice would be an tube of 125-mm OD and 30-mm wall thickness (or 65-mm ID). This would be best done with a long bar from which the appropriate length would be parted off once all other lathe-work is complete.

b) The operations required to machine the part are listed below. Each is broken into multiple individual processes as needed to create the respective feature.

Op-1 Create outer axisymmetric surfaces
1. Fixturing: Extend 275 mm or slightly more from the chuck of a lathe.
2. OD turn entire length (260 mm minimum) to 120 mm outer diameter in two passes: one rough (to 121 mm diameter) and one finish (to 120 mm diameter).
3. OD turn right-hand portion to 80 mm outer diameter in seven passes: six rough passes of equal depths of cut down to 81 mm diameter and one finish pass to 80 mm diameter; create chamfer at diameter transition.

Op-2 Create inner axisymmetric surfaces
1. Fixturing: Keep chucked in lathe.
2. Bore/ID-turn entire length (260 mm minimum) to 70 mm inner diameter in two passes: one rough (to 69 mm diameter) and one finish (to 70 mm diameter).

Op-3 Cut-off
1. Fixturing: Keep chucked in lathe.
2. Part/cut-off to remove 260-mm length from raw tube stock to remain in lathe chuck.

Op-4 Create slot and drilled holes
1. Fixturing: transfer cut-off part to a machining center with a rotary clamp.
2. Cut slot with 20-mm diameter end cutting (for plunging) end mill.
3. Drill first hole in line with slot.
4. Drill three additional holes with a 90° part rotation between each.
5. Using four additional part rotations, orient and tap each of the four holes.

The six processes are:
(1) OD turning (2) Boring/ID-turning (3) Cut-off (4) Slot end milling (5) Drilling (6) Tapping
2.3

**Given:**
- orthogonal cutting
- orthogonal rake angle, \( \gamma_o = 10^\circ \)
- uncut chip thickness, \( h = 0.20 \) mm
- cutting speed, \( V = 50 \) m/min
- chip thickness ratio, \( r_h = 0.5^\circ \)

a) By definition, the chip thickness ratio is

\[ r_h = \frac{h}{h_c}. \]

Therefore,

\[ h_c = \frac{h}{r_h}. \]

Substituting the given value for uncut chip thickness \( h \), the final result (in mm) is

\[ h_c = \frac{0.20}{0.5} = 0.40 \] mm.

b) The chip velocity is related to the cutting velocity by the chip ratio as

\[ V_c = r_h V. \]

Substituting known values, the final result (in m/min) is

\[ V_c = (0.5)(50) = 25 \] m/min.

c) The chip thickness ratio can also be written in terms of the shear angle and rake angle as

\[ r_h = \frac{\sin \phi_o}{\cos(\phi_o - \gamma_o)}. \]

Rearranging,

\[ \sin \phi_o = r_h \cos(\phi_o - \gamma_o). \]

The shear angle can be found in two ways as follows:

The \( \cos(\phi_o - \gamma_o) \) terms can be transformed, using an angle-difference trigonometric identity, to

\[ \cos(\phi_o - \gamma_o) = \cos \phi_o \cos \gamma_o + \sin \phi_o \sin \gamma_o. \]

Therefore,

\[ \sin \phi_o = r_h \left( \cos \phi_o \cos \gamma_o + \sin \phi_o \sin \gamma_o \right). \]

Dividing through by \( \cos \phi_o \) yields

\[ \tan \phi_o = r_h \left( \cos \gamma_o + \tan \phi \sin \gamma_o \right). \]

Grouping coefficient of \( \tan \phi_o \), then results in

\[ \tan \phi_o \left( 1 - r_h \sin \gamma_o \right) = r_h \cos \gamma_o. \]

The final expression for shear angle is

\[ \phi_o = \tan^{-1} \left[ \frac{r_h \cos \gamma_o}{1 - r_h \sin \gamma_o} \right]. \]

Substituting known values, the final result is

\[ \phi_o = \tan^{-1} \left[ \frac{0.20 \cos 10^\circ}{1 - 0.20 \sin 10^\circ} \right]. \]

By taking the inverse sine of each side, an expression for \( \phi_o \) in terms of \( \phi_o \) results as

\[ \phi_o = \sin^{-1} \left[ r_h \cos(\phi_o - \gamma_o) \right]. \]

Substituting known values yields

\[ \phi_o = \sin^{-1} \left[ 0.5 \cos(\phi_o - 10^\circ) \right]. \]

The result can then be found by simple iteration. It is known that shear angle cannot be greater than the minimum-energy result of

\[ \frac{90^\circ + \gamma_o}{2} = 50^\circ. \]

Therefore, a good guess may be slightly below that, such as 45°. The first iteration is

\[ \phi_o = \sin^{-1} \left[ 0.5 \cos(45^\circ - 10^\circ) \right] = 24.17^\circ. \]

Subsequent iterations are

\[ \phi_o = \sin^{-1} \left[ 0.5 \cos(24.17^\circ - 10^\circ) \right] = 29.00^\circ. \]
\[ \phi_o = \tan^{-1} \left( \frac{0.5 \cos(10^\circ)}{1 - 0.5 \sin(10^\circ)} \right) = 28.3^\circ. \]

\[ \phi_o = \sin^{-1} \left( 0.5 \cos(29.00^\circ - 10^\circ) \right) = 28.21^\circ \]
\[ \phi_o = \sin^{-1} \left( 0.5 \cos(28.21^\circ - 10^\circ) \right) = 28.36^\circ \]
\[ \phi_o = \sin^{-1} \left( 0.5 \cos(28.36^\circ - 10^\circ) \right) = 28.33^\circ \]
\[ \phi_o = \sin^{-1} \left( 0.5 \cos(28.33^\circ - 10^\circ) \right) = 28.34^\circ \]

The final result is \( \phi_o = 28.34^\circ \).

**For the remainder of the problem, assume the answer to part (c) is \( \phi_o = 30^\circ \).**

**d)** The shear velocity is related to the cutting velocity as

\[ V_s = \frac{\cos \gamma}{\cos(\phi_o - \gamma_o)} V. \]

Substituting known values, including the value given for shear angle of 30°, the final result (in m/min) is

\[ V_s = \frac{\cos(10^\circ)}{\cos(30^\circ - 10^\circ)} 50 = 52.4. \]

**e)** The Lee and Shaffer model is

\[ \phi_o = 45^\circ + \gamma_o - \beta. \]

Solving for \( \beta \) and substituting known values, the final result is

\[ \beta = 45^\circ + \gamma_o - \phi_o = 45^\circ + 10^\circ - 30^\circ = 25^\circ. \]